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NEW PRINCIPLES IN AGRICULTURAL PLANT-BREEDING.

THE theory of mutation is directly opposed to the current view of an origin of species and races by means of slow and gradual changes. It assumes a saltatory transformation of one form into another, or rather, since the parent form does not disappear in the process, it claims the production of new forms by lateral saults from the main stem. In this way the same species may produce quite a number of new types, either simultaneously or at short or long intervals.

This new principle finds its application in nature as well as in agricultural and horticultural practice. It is now rapidly gaining acknowledgment among biologists, but many plant-breeders still keep to the old view. They prefer a slow amelioration of their races to the more rapid improvement, of which the theory of mutation points out the possibility. Their vast experience supports their view, at least apparently, and until some time ago, no direct facts could be adduced to give proof of its inaccuracy. It is always venturesome to oppose a scientific theory to practical experience, and such a process can only be successful if it is possible to give a full and evident explanation of the facts on which that experience was based.

In the case of plant-breeding, however, new discoveries concerning the variability of cereals and other crops have been made of late. Dr. Nilsson, the director of the Agricultural Experiment Station at Svalöf, Sweden, has found that this variability wholly complies with the views propounded by the theory of mutation and does not support the conception of slow changes as a means of improving agricultural races. During the last fifteen years he has produced quite a number of new and valuable races which have already supplanted the old types on numerous farms of Sweden, and which are now being introduced into Germany and other European countries, on a large scale. All his races have been produced by a single choice for each; after that they proved constant at once and had only to be multiplied and to be compared with the existing forms.

Theory and practice thus being in perfect harmony, it appears desirable to submit the opposed views to a sharp criticism. The question naturally arises, in how far the processes now generally in use may be modified advantageously by the introduction of the new principle. It is evident that the reduction of the selection, which now embraces a series of years, to one single choice, must simplify and shorten the work, and that on this account, the new ideas have a distinct claim to consideration.

The current view assumes that varieties of plants can be changed artificially in such ways as the breeder may choose. It is claimed that existing characters can be modified, and that new qualities can be forced upon the plants. Environmental influences and selection are the means employed. From six to ten generations are said to be generally sufficient to fix the descendants of the originally chosen individuals in their new ways. This lapse of time is required to prevent the new varieties from reverting to the former condition. When once stability is secured, the variety may be counted upon to keep true to its new qualities.

This conception originated at a time when the different types of variability were still unknown. It combines facts belonging to contrasting phenomena into one single process, and therefore must seem inviolable only as long as it is not possible to make that distinction. Modern science, however, has shown that variability embraces two main subdivisions, which follow quite different laws. One of them is now called fluctuating variability, or fluctuability, and the other mutability. Fluctuations are the slow and gradual changes, which are always present in every cultivated race or wild species. They are affording a rich material for selection and improvement, but do not lead to constant varieties. Their main example is the improvement of sugar-beets. Mutations, on the other hand, are saltatory changes, which at once give birth to new and constant forms. These, if kept free from the contamination by pollen of the parent species, do not revert to it, and do not need any further selection. Usually, they are even so uniform, that they do not afford the material for such selection. Fluctuations never fail, and any large set of seedlings of a common origin will show them. But mutations are rare, and, as a rule, occur only from time to time. Their products, however, will multiply and keep their standing during successive generations, at least wherever the new characters are of a useful or harmless nature. In this way the number of mutated types within a given species or variety may increase in the lapse of time, even until the old form becomes changed into a group of more or less numerous mutative units. Numerous wild species have been recognized of late in this condition, and almost all the prominent agricultural crops comply with this rule. Varieties, as they are called, of cereals, of corn, of clover and of many other plants are seen to be multiform, each of them comprising a larger or smaller number of well-defined forms. These units, when isolated, prove uniform and constant, and afford material for selection quite different from that afforded by the fluctuating variability.

In this discussion I am not concerned with artificial hybridizations and hybrids. They are only exceptionally of prominent value in the production of such varieties as are usually propagated from seed. Natural hybridizations, on the other hand, are occurring in the fields more frequently than is generally assumed, and have a distinct influence on the practical significance of mutability. It is easy to understand this. As soon as nature has produced, in a field, a new type which is distinguished from the main sort by some distinct character, this new character can be transferred by accidental crosses on other constituents of the variety, and, in the long run, perhaps, on all of them. By this means the new quality will be combined with all of the types already existing within the variety, and a series of new forms will be produced. It is easily seen that a single mutation, by means of such crosses, may be the beginning of a number of new elementary forms, some of which may have useful and others indifferent characters. This is the process by which the present state of multiformity of most of our agricultural varieties has originated, according to the theory of mutation and according to the facts discovered at Svalöf, which now so plainly support this view.

I have cited the selection of the sugar-beets as an instance of utilizing fluctuating variability. Setting aside the initial choice of this race by Louis Vilmorin, concerning which no historical dates have been recorded, this selection is exclusively concerned with qualities which are always varying, and which, as far as they have been studied, follow the ordinary laws of fluctuating variability, first discovered by Quetelet for men, and since applied to the animal and vegetable kingdoms by Galton and others. The form and branching of the roots, the character of the foliage, and mainly the sugar-percentage, are the points which have to be improved by selection. The range of the variability increases in a corresponding degree with the number of specimens investigated, and nowadays the selection is usually made out of some hundred thousands of individuals whose sugar-percentage has been determined by polarization. Out of these numbers some few of the very best are chosen yearly and only by means of this very sharp selection the races can be kept up to their present high standard. Discontinuing the selection would mean to allow the race to return to its former comparatively poor condition, and no intelligent farmer would sow such seeds. More than thirty generations have improved the beets, but there is not the least sign that this improvement should have led to the production of constant and independent races. The capacity of producing more sugar cannot be enforced upon the race, and the only work of the breeder is to select, in each generation, those individuals which, from the unknown influence of environmental conditions, seem to him the most apt to give a progeny which will, temporarily, yield a rich harvest of sugar.

Contrasting with this process of selecting sugar-beets is the work of the horticulturists in producing new varieties of seed-plants. As already mentioned, I am not concerned here with artificial hybridization, which, in the field of horticulture, mainly produces varieties which must be propagated in the vegetative way in order to remain constant. In vegetables and garden flowers new varieties, as a rule, arise suddenly, and historical records are at hand which give the origin for a considerable number of them. Every year the catalogues of the prominent nurseries bring some novelties. These are all produced by leaps and are, from their first appearance, isolated and subjected to the process of selection in order to "fix" them, as the phrase goes. This "fixing," however, is only a purifying from foreign admixtures, which usually are the consequence of the partial pollination of the first mutants by their neighbors, since it is, as a rule, impossible, or at least hazardous, to isolate the mutants themselves by transplanting them to a distant spot. It requires four or five or more years, according to the fertility of the species. There is no such thing as a theoretical fixing of initially unfixed characters, and whenever the isolation is performed by scientific methods, insuring complete self-fertilization, the new race is, at once, found constant and in no need of "fixing.".

In nature new species originate in the same way, at least as far as our present limited knowledge goes. I have had the privilege of cultivating in my experiment garden, a species which was then in a mutative condition. It is the large-flowered evening primrose, or evening primrose of Lamarck. It has produced about a dozen new species and is repeating the same process of mutability, now, in numerous gardens of the United States and elsewhere. The new types spring from it by leaps and laterally; they are, as a rule, constant from the very beginning, the only condition being that the flowers of the first mutant are artificially kept free from visiting insects and purely fertilized. No preparatory changes and no intermediates are observed, and the mutations are always complete, never producing half-way steps which must be repeated in order to reach the full mutation. They do not need any guidance or any help, they cannot be improved or fixed, since from their very first appearance they are a pure, new type. Moreover, they are constant from seed, never reverting to the parental type, but subjected, like this, to progressive mutations. Some of them excel the evening primrose of Lamarck by distinct qualities, others are weaker, or deficient in some point. If they had originated in a nursery and not in an experimental garden, the latter would have been thrown away and only the stout, profusely flowering types, and perhaps the dwarfish variety, would have been selected for multiplication and introduction into trade.

The experiments at the above-named Swedish experiment station lead to the conclusion that among cereals and other large agricultural crops new types arise in the same way as in horticulture and in experimental work. Moreover, they show that the process of slow and gradual improvement of races is only an imaginary one. There is no doubt that by continued selection excellent races have been produced and can still be secured. But this, in itself, is no proof of slow improvement, as we shall soon see.

At Svalöf this method of repeated selection was followed in the beginning, because it was then the prevailing method among European breeders. It is now twenty years since the station was founded, and during the first period of its work, embracing about five years, a great number of varieties of cereals were subjected to this selection. The result has been the same which, as a fact, was the result of this kind of breeding in Germany, but which had never clearly been pointed out. Some few varieties could be improved and yielded excellent new types, of which some have since been introduced into Swedish agriculture and are now prominent races in the southern and middle parts of that country. But by far the larger number of the experiments yielded no results at all and the most striking among them were those with the Chevalier barley which, in Middle Sweden, is a fine brewers' barley, but exposed to failures during unfavorable summers on account of its slender stems. No amount of care, no endurance, no treatment and no selection were able to secure firmer stems in this barley, and since this was the improvement which the Swedish farmers desired above all, the whole method of continuous selection necessarily fell into discredit. Good results were exceptions, and therefore the principle was not one that could be relied upon. The idea suggested itself that those exceptions might be due to wholly different and accidentally active causes and that it would be better to seek for these causes than to continue a method of such doubtful significance.

In order to discover these suspected causes, selection experiments were started anew and on a large scale. About a thousand samples were chosen in the grain fields of the station, each comprising a certain number of ears which were estimated to differ from the main type of their variety in the same valuable quality. Each sample was sowed separately and the next summer the lots could be compared with one another. It was hoped that each lot would be uniform and different from the others. Nothing of the kind, however, was seen, with only some few exceptions. All the lots were apparently as variable as the variety from which they had been chosen and only these few were really uniform. Exact records had been kept concerning the chosen samples and, especially, the number of ears had been entered for each. This excellent book-keeping led to the discovery of the fact that only those lots were really uniform on which only the kernels of one single ear had been sown. Hence the conclusion that the mixture of ears of apparently similar characters was a principal fault of the prevailing method. No similarity can be relied upon, and only the progeny can decide concerning purity and agricultural value.

As soon as this fact was discovered, it was elevated to the rank of a leading principle and tested on as large a scale as possible. Again, a thousand samples were chosen in the field, but this time each sample consisted of one ear only. The kernels of each ear were sown separately, and the next year the result surpassed the highest expectations. Instead of a hopeless multiformity, uniformity now prevailed. With some few exceptions each lot was uniform. Of course, there were fluctuating differences. But these proved to be very small, so small as not to afford any material for further selection or even to justify a desire for purification. The exceptions have since been proven to have been caused by the accidental choice of hybrid ears. Leaving these aside, the result was that the progeny of single ears is pure but that of mixed ears impure, and all subsequent experiments have absolutely justified this conclusion. In this way, by single-ear-selection, as it is called, at once numerous new races can be isolated from the ordinary variable or rather multiform varieties.

Once isolated, such single-parent races are constant from seed and remain true to their type. They can be multiplied without further selection and, therefore, very rapidly. Some five or six years are, as a rule, sufficient to produce from one chosen initial individual the whole quantity required for advantageous introduction into agriculture at large. It is, however, manifest that not all the isolated races will be real improvements. Hence it follows that they have to be compared with one another and with the existing varieties, in order to find out which among them are the very best. This work has been found to be far more difficult and time-consuming than the initial selection and is now to be considered as the chief task of the station at Svalöf and of all breeders who will work along the same lines. On the other hand, it has been proved that the variability among these isolated races is so great and goes on in so many different directions as to comply with almost all the desires of the breeders. The experiment fields of the station can be said to be an exhibit on which each farmer can find and choose exactly the varieties which will be suitable for his farm and his industrial needs. Even a stiff-halmed barley was among the first products of this new method; it is now known as Primus barley and largely grown all over the middle part of Sweden.

In this way single-ear selection and separate culture is, now, the principle of all plant-breeding at Svalöf. It is the same idea which has been applied by W. M. Hays at the State Experiment Station of Minnesota to the improvement of the local wheats, Fife and Blue Stem, of that State, and which there has given such remarkable results. But at Svalöf the works rests on so broad an experimental basis, that all the details of the method have been thoroughly cleared up, and that it may be applied to any other agricultural crop with full confidence in its success.

Moreover, it gives a very simple answer to the question as to the cause of the exceptional results secured by repeated selection. These start from samples of ears, as is the custom in Germany and elsewhere. Each ear, if sown separately, would have given a uniform progeny; mixed together they give a mixed progeny. Out of this mixture the continued selection will first eliminate some of the strains, and then gradually restrict the number, until, at last, only the progeny of one of the initially chosen ears remains. Then the race will be as pure and constant as it will be excellent. But it is evident that quite the same result could have been obtained without the repetition of the selection, if only the kernels of each initial ear had been sown separately.

Of course the principle applies to the breeding of corn as well. Here the newly introduced method of selection chooses and separates the ears, and compares their progeny after separate sowing. The principle would be exactly the same and at once yield the same uniform and constant races as at Svalöf, were it not for the wind-pollination of the species. No repeated selection would be needed in order to obtain constant races, nor would it be even possible but for the elimination of the contaminating effects of natural cross-fertilization. Hence we may conclude that the now prevailing method of continued selection has, as a fact, nothing to do with real improvement, but has only to improve the races by purifying them from vicinistic impurities. The selection of the best ears for seed-corn is quite another question, since it does not affect the race-production, but has simply to eliminate the ears which, through fluctuating variability, least comply with the demands of the planting machine or the planter which can plant regularly only when the seeds are uniform in size and shape. It has also to eliminate the ears of insufficient vitality and of some other inferior qualities. If a method could be found to select corn-ears on the paternal side, as well as on the maternal, all repeated selection would probably be superfluous in the building of new races.

I have indulged in these suggestions only to show the wide applicability and the probably high value of the principle of one year selection without repetition. In numerous cases it will simplify and shorten the work of the breeder. But it excels the current views mainly in as much as it gives a truer and clearer conception of the variability of agricultural plants, and thus will soon become a rich source of methodical improvements in all plant-breeding.

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